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A DELPHI STUDY OF ADVANCED MATERIALS DEVELOPMENTS

Report No. 87-272-K

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ABSTRACT

A Delphi study was undertaken with the purpose of producing a technological forecast in the area of advanced industrial materials. Specific areas addressed were ceramics, plastics, metals, electrolytic materials and superconducting materials. Details of the methodology, the study's conduct and results are presented.

The results are intended to be useful to the Research Division in facilitating the transfer of technology to Hydro's end users and useful to the Market Services and Development Division in identifying effects of new materials on Hydro's markets. They should also serve as a starting point for identifying specific applications of new materials within the Hydro operating system.

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EXECUTIVE SUMMARY

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A Delphi study was undertaken with the purpose of producing a technological forecast in the area of advanced industrial materials. The forecast is intended to be useful to the Research Division in its role of facilitating the transfer of technology to Hydro's end users, and useful to the Market Services and Development Division in identifying effects of new materials on Hydro's markets. It should also assist in identifying applications of new materials in the power system.

Specific areas addressed were ceramics, plastics, metals, electrolytic materials and superconducting materials. Some general areas not included in these categories were also considered.

The Delphi technique involves designing a questionnaire which can be answered over a number of rounds by a group of suitably qualified participants. Personnel from Corporate Programming, Economics and Forecasts, Market Services and Development, and from Research assisted with the questionnaire design. Though the main body of participants came from the Research Division, Corporate Programming, Design and Development (Generation), Design and Development (Transmission), and Market Services and Development were also represented. The study was carried out in June and July of 1987 and explored 15 years into the future.

In general the responses to the questions showed a strong convergence over the course of the study. This indicates a good consensus on the forecast results. An exception to this was the electrolytic-materials section. This likely reflects the current state of flux in that area.

Results from each section of the study are summarized below. These are not intended as definitive predictions of the future but rather as aids to planning for the future. The reader in-

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terested in using them in this capacity should also consult Section 3 and Appendices C and D in which the results appear more fully.

Ceramics

- The auto industry will account for the greatest increase in the use of ceramics in the next decade, followed by the electronics industry.
- No new types of ceramic engines are expected to gain significant market share in the next 15 years.
- The most significant obstacle to the use of high performance ceramics is that the reliability is inconsistent.
- Electrotechnologies will play a major role in the pre-sintering part of production in about six years, while microwave heating will play a major part in about eight years.

Plastics

- Plastic will become the predominant car body material 10 to 15 years from now.
- Compared to the metal being replaced, plastic production will require between one-half and three-quarters of the electrical energy.
- Plastics use will increase significantly, both in food and beverage packaging and in under-the-hood auto applications in 6 to 10 years.
- The use of conductive polymers for bulk electric conductors is not probable within the next 15 years.

Metals

- A modest decline will occur in Ontario's copper and nickel industries over the next 15 years.
- Zinc mining will stay at current levels.
- Steel production as a fraction of the gross provincial product will decline to between 60 and 80% of its current value in 15 years.

Electrolytic Materials

- Of the six sections in the study, this section showed the least third-round convergence. This probably reflects a situation in which a number of breakthroughs are being made in unrelated areas. A consensus on their relative importance and final consequence has not yet developed.

- There is some indication of optimism in the long term both for the solid oxide fuel cell and for the sodium-sulphur battery.

Superconducting Materials

- Both the limited current carrying capacity and the poor mechanical properties of the new superconducting materials are significant but tractable problems.

- Superconducting coils for storing electrical energy, superconducting generators, and superconducting components for control devices and fault limiters will become cost effective in 10 to 15 years.

- No consensus could be reached on the timing of the use of superconducting materials for bulk transmission of electricity.

- Robust room temperature superconductivity might impact on Ontario Hydro's operation by increasing the use of electricity in transportation and by making load shifting more practical.

General

- Fusion will not be a serious planning option for at least 15 years.

- New materials that come into use in the next 15 years will on the average require 5 to 25% more electrical energy in their manufacture than the materials they replace.

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To Dr. D. Mills
Director of Research

A DELPHI STUDY OF ADVANCED MATERIALS DEVELOPMENTS

1. TECHNOLOGY FORECASTING AND THE DELPHI METHOD

1.1 Technology Forecasting

Though systematic methods of forecast such as extrapolation, employing conditional probabilities and polling informed individuals were suggested in the literature/1/ as long ago as 1794, technology forecasting coalesced into a discipline less than fifty years ago. It currently encompasses a collection of diverse forecast methods. These may be categorized in several ways but it is convenient to classify them broadly as intuitive, extrapolatory and analytical. Techniques from each of these three classifications have been applied with various degrees of sophistication by companies formulating research strategies and preparing themselves for future market opportunities.

Generally speaking the extrapolatory methods are appropriate to the forecast of a few important numerical parameters and rely on curve fitting and statistical analysis.

The analytical studies employ various techniques but are typically very intensive and focussed. They are most appropriately applied to investigate a fairly narrow field.

Intuitive techniques involve the collection and synthesis of informed opinion and as such are applicable to broad areas of investigation. One of the simplest examples of the intuitive method is a poll of knowledgeable people concerning a particular technological development. Results of this can be surprisingly good as well as surprisingly bad. This is consistent with the idea that expert opinion is fundamentally sound but is sometimes badly flawed in its expression. Fears of self-contradiction, of conflict with a colleague, or of ridicule can all contribute to this situation. A refinement which assures the anonymity of the participant and at the same time allows constructive feedback from his peers was developed by Helmer and Dalkey at the Rand Corporation in the early fifties/2/. It was further developed by Gordon and Helmer in the early sixties/3/ and in that form became very popular. It is known as the Delphi method.

1.2 The Delphi Method

This method involves constructing a questionnaire from questions of a particular type. As well as being carefully worded the questions must be such that an individual response can be meaningfully compared with the group response. This is usually done by making the possible responses cover a continuous range.

The respondents to the questionnaire should be well informed in the appropriate area but the literature/4,5/ suggests that a high degree of expertise is not necessary. The minimum number

of participants to ensure a good group performance is somewhat dependent on the study design. Experiments by Brockhoff/6/, however, suggest that groups as small as four can perform well. After the participants have replied to the questionnaire a statistical analysis is carried out on the responses. They are then asked to respond to the questionnaire again, this time with the knowledge of the relative position of their first-round answers with respect to the group response. In all cases the participants are encouraged to make relevant comments and are free to change their response from the previous round. If there is substantial disagreement with the group response the individual may be required to write down factors he thinks other participants are missing or to appropriately adjust his own response.

The third round is essentially the same as the second with the respondent being able to see comments made by the group as well as the position of his answer relative to those of the group. The process is often terminated after the third round though it is sometimes continued for one or two more rounds.

The final result of the study is a set of answers to the questions posed, along with some indication of the degree of consensus on any particular response and a collection of comments on the various areas. Many of the comments have stand-alone value as they present points that otherwise would have been missed.

The Delphi method is a widely used and a widely respected method of forecasting. It is, however, not without critics. The strengths and weaknesses of the method and the criticisms leveled against it are discussed more fully in Appendix A.

2. THE CURRENT STUDY

2.1 Background and Purpose

Many recent studies suggest that technology is currently undergoing a period of very broad and rapid change. Though several areas appear regularly on various lists of developing technologies, three appear consistently. They are computing, biotechnology and advanced materials. Each of these areas is huge, encompasses several unrelated technologies and is moving rapidly. It would take an extremely ambitious effort to attempt a forecast of all three areas in sufficient detail to produce a useful planning tool.

Though all three areas are of immense importance, it was decided that the most useful approach would be to focus this particular study on the area of advanced materials. This area is having a widening impact on our industrial customers. The use of ceramics and plastics in the auto industry for instance has implications not only for electricity use there but also in Ontario metals industries. Advanced materials also have the potential to aid Ontario Hydro in the continued production of cheap reliable electricity. In some cases aging plant components will be replaced by components of greater durability. In other cases the superior properties of the new materials will facilitate entirely novel ways of increasing system efficiency.

The purpose of this study is then to produce a technology forecast focussed on the area of advanced materials. The forecast should be useful to the Research Division in fulfilling its role of facilitating the transfer of technology to Hydro's end users and useful to the Market Services and Development Division in identifying effects of new materials on Hydro's markets. It should also serve as a starting point for identifying specific applications of new materials within the Hydro operating system.

2.2 Study Mechanics

The study consisted of three rounds each taking two weeks. The first week was taken up by the completion of the questionnaire, while the second week was required for evaluation of the results and preparation for the subsequent round.

The study was divided into six sections. These covered the areas of Ceramics, Plastics, Metals, Electrolytic Materials and Superconducting Materials. A final section was included which was made up of general questions and questions which did not fit into the previous five categories.

A few questions did not fit the Delphi format. These were of a general information gathering nature and required only one round for completion.

The questions were formulated after an extensive literature search followed up by consultations with Research Division specialists in relevant areas. Neil Burnett of Market Services and Development, Lily Buja Bijunas of Economics and Forecasts and Mark Khanna of Corporate Programming also provided valuable input and guidance in this regard.

Twenty-nine people agreed to be respondents to the questionnaire. Of these, 25 were from the Research Division. Of the four participants external to the Research Division one each came from Market Services and Development, Corporate Programming, Design and Development (Transmission) and Design and Development (Generation). A complete list of the respondents and the sections they responded to is given in Appendix B.

In all the Delphi type questions, the respondents were required to pick one answer from a list of five. In addition they were required to provide short comments in support of their choice. At the end of each round the results were tabulated for each question and a statistical analysis was carried out. In the next round the participant's previous round response was marked by an arrow or a circle. An arrow indicated that the response was significantly different from the majority response and the respondent was asked to move his response in the direction of the arrow or to write down some facts other respondents might have missed. A circle indicated that the response was in line with the majority of responses. In this case, the participant could leave his answer unchanged or move it in response to the comments of the others.

It was found that the answers to all of the Delphi questions showed convergence over the three rounds. An example of this for a typical question is shown in Figure 1. The third round answers along with comments made throughout, are shown in Appendix D.

3. CONCLUSION AND RESULTS

3.1 Conclusions

With the exception of the electrolytic-materials section the convergence in responses was very strong. The results of the study should be appropriate to the purposes outlined in section 2.1. The study is then a success both from a technical and from a practical, point of view.

The study is spread over six more or less distinct areas. The results relevant to each area are summarized in the six following sections.

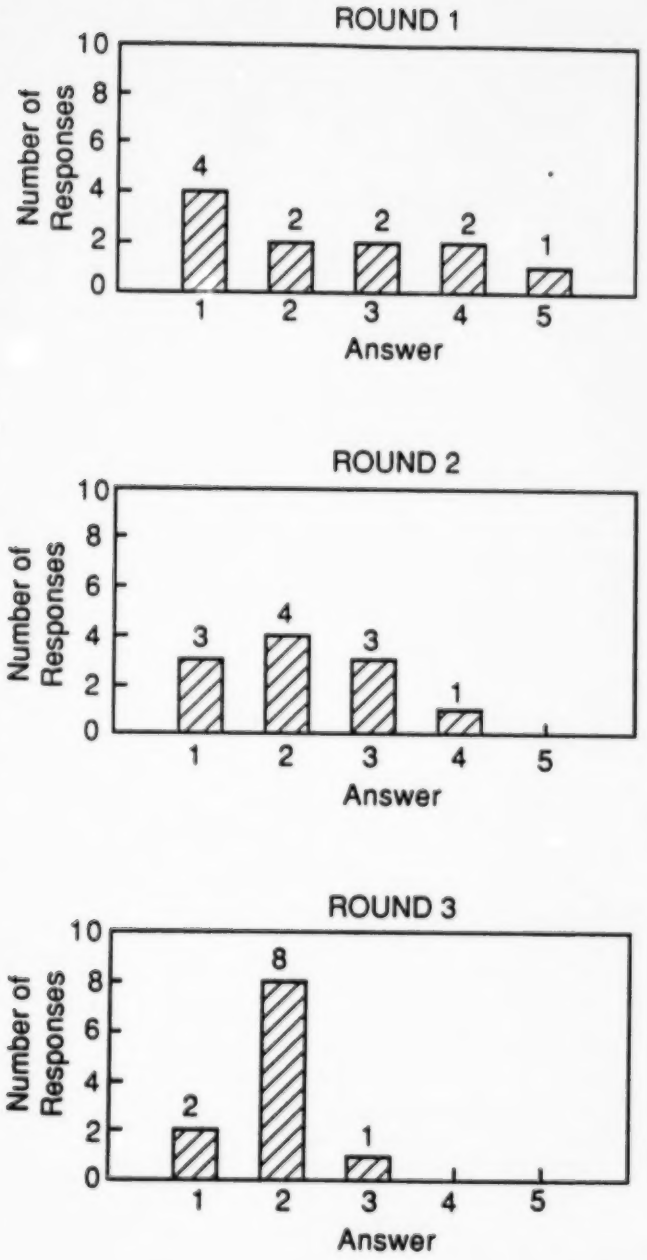

FIGURE 1

RESPONSES TO QUESTION S1 OVER THE THREE ROUNDS

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The reader who is interested in using these study results as planning aids should also consult Appendix C which gives a question-by-question summary of the results and Appendix D which contains the questionnaire used complete with a summary of the third round results and the comments made by respondents over the three rounds.

3.2 Summary of Results from the Ceramics Section

Though no novel types of ceramic engines are expected to gain significant market share in the next 15 years the auto industry will account for the greatest increase in the use of ceramics in the next decade followed by the electronics industry. The most significant impediment to the use of high performance ceramics is reproducible reliability. The cost of high performance ceramics will drop to half the current level in about 10 years. Electrotechnologies will play a major role in the pre-sintering part of production in about six years while microwave heating will play a major part in sintering in about eight years.

3.3 Summary of Results from the Plastics Section

There was unanimous agreement that plastics would become the predominant car body material 10 to 15 years from now and near unanimous agreement that in production plastics would require between one-half and three-quarters of the electrical energy of that required by the metal being replaced. Plastic use is predicted to increase significantly both in food and beverage packaging and in under-the-hood auto use in from 6 to 10 years but use of conductive polymers for bulk electric conductors was not seen as probable within the next 15 years.

3.4 Summary of Results from the Metals Section

There is strong agreement on a modest decline in Ontario's copper and nickel industry over the next fifteen years with zinc mining predicted to stay at current levels. From an energy use standpoint the most significant prediction is that steel production as a fraction of gross provincial product will decline to between 60 and 80% of its current value in fifteen years.

3.5 Summary of Results from the Electrolytic-Materials Section

Of the six sections in the Delphi study the electrolytic materials section showed the least third round convergence. This probably reflects a situation in which a number of breakthroughs are being made in unrelated areas and in which a consensus on their relative importance and final consequence has not yet developed.

The third round results are too widely spread and the comments too diverse to draw definitive conclusions. There is however some indication of optimism in the long term both for the solid oxide fuel cell and for the sodium-sulphur battery.

3.6 Summary of Results from the Superconductivity Section

Both the limited current capacity and the poor mechanical properties of the new superconducting material are seen as significant but tractable problems. For three of the four electric power system applications whose timing was queried, the majority response was, "between 10 and 15 years from now". These three were diurnal energy storage, control devices and generators. The fourth application, transmission, received a bimodal response which is indicative of a lack of consensus and an uncertainty concerning this application.

Respondents felt that robust room-temperature superconductivity might impact on Hydro's operation by increasing the use of electricity in transportation and by making load-shifting more practical.

3.7 Summary of Results from the General Section

There is a good consensus both that fusion will not be a serious planning option for electricity for at least 15 years and that the new materials that come into use in the next 15 years will on the average require 5 to 25% more electrical energy in their manufacture than the materials they replace.

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APPENDIX A

A DELPHI CRITIQUE

The Delphi method was conceived as a refinement to the expert-panel discussion. One of its merits is that it successfully permits the interaction of the participant's opinions while avoiding interference from the interaction of their personalities. Since the participants can respond (within limits) as their own schedules permit, disruption of valuable personnel's activities is minimized. As well, since the overall process is spread over a much longer time than an expert-panel discussion would be, contrary viewpoints are given a better chance of being evaluated on their merits. The Delphi format gives a written record not only of the response and the degree of consensus among experts but also to some extent, the rationale involved in coming to the final result.

The method is very accessible and easy to use. It is also easy to misuse. Several questionable studies are available as examples. One, for instance, involving questions concerning the best safety standards for asbestos was carried out using a participant group composed largely of people from the asbestos industry/7/. While these are proof that the method can be abused they are not proof that the method is unsound.

The use of the word, "Delphi" causes some problems. Some find the application of this word to a scheme of iterative polling presumptuous and overblown. On the other hand the mystique of the word is sufficient to tempt some to apply the name to questionnaire exercises with little resemblance to the conventional Delphi method. Though the choice of name may be unfortunate it has been with the method since its origin and would be difficult to change now.

One of the most frequent criticisms of the Delphi method is that there is little proof of its accuracy. This is of course true of any method of predicting the future. There have, however, been several indications that the Delphi method does work. Dalkey/8/ conducted several experimental Delphi studies in which participants were asked almanac-type questions (e.g. what was the population of Tokyo in 1950). It was found that successive rounds not only produced convergence but produced convergence toward the true values. Campbell/9/ conducted experiments in which he arbitrarily divided participant groups in half. One half forecast the value of a number of business indicators one year into the future using group discussion and trend analysis. The other half made a similar forecast using the Delphi method. For two-thirds of the quantities predicted, the Delphi forecast gave values closer to those that were realized than the alternative methods. Ament/10/ carried out a study in 1970 of Delphi predictions that had been made in previous years. For those events which had been predicted to occur by 1970 he found reasonable agreement with reality.

Another area in which criticism of Delphi studies sometimes occurs is in the selection of experts for the respondent group. The criticism in this case usually comes from someone whose favorite expert did not participate. Several studies/4,5/ indicate, however, that using intelligent, well informed individuals does not give significantly different results than using bona fide experts.

Though literature critical of the Delphi method exists/11/ it is difficult to find any

studies which purport to prove that the Delphi technique is less effective in predicting the future than other methods. On the other hand there have been several studies/8,9,10/ indicating the contrary.

Quite apart from this it must be remembered that a forecast is a planning tool whose purpose is to stimulate intelligent thought about the future, not to define it. To quote Sylvia Ostry, former Chief Economist for the Organization for Economic Co-operation and Development, "Anyone who believes a forecast is a novice who misunderstands the purpose of forecasting. It is an informational tool".

One of the great problems of forecasting is to ensure that the end product does stimulate thought about the forecast area both among planners and those who will be affected by those plans. One of the virtues of the Delphi technique is that people from these groups often can be included among the participants, enhancing the likelihood that the information will be absorbed and that there will be commitment to decisions based on it.

APPENDIX B

STUDY PARTICIPANTS

Participant	Division	Study Section
N. Anyas-Weiss	Research	Superconducting Materials General
I.S. Balbaa	Research	Ceramics Superconducting Materials General
G. Bellamy	Research	Metals General
M.R. Booth	Research	Superconducting Materials General
J-M Braun	Research	Ceramics Plastics General
N.C. Burnett	Market Services and Development	Ceramics
T.P. Byrne	Research	Superconducting Materials General
F.Y. Chu	Research	Superconducting Materials General
D.J. Dodd	Research	Electrolytic Materials General
M.A. Habayeb	Research	Plastics General
S.M. Harvey	Research	Superconducting Materials General
E.T. Ho	Research	Metals General
D.J. Horrocks	Design and Development (Transmission)	Superconducting Materials
R.K. Kalia	Research	Electrolytic Materials General

M. Khanna	Corporate Programming	Superconducting Materials
S. Lawson	Research	Metals General
D.C. Lee	Research	Superconducting Materials General
M. Leger	Research	Metals General
P. Mayer	Research	Ceramics Metals General
M.S. Mozes	Research	Electrolytic Materials General
P.K. Mukerjee	Research	Superconducting Materials General
S.J. Oda	Research	Ceramics Plastics General
R.D. Quick	Design and Development (Generation)	Electrolytic Materials
R.A. Reesor	Research	Ceramics Metals
C.J. Simpson	Research	Ceramics Metals Electrolytic Materials General
D.J. Stonkus	Research	Plastics General
J.T. Strack	Research	Ceramics General
G.L. Vascotto	Research	Superconducting Materials General
A.S. Williamson	Research	Plastics General

APPENDIX C

QUESTION BY QUESTION SUMMARY OF RESULTS

C.1 Ceramics Questions - Overview

The ceramics section of the questionnaire consists of seven questions. All but the last question, C7, are of the usual Delphi type and were repeated for three rounds. C7 was completed after the first round. Eight participants responded to all of the questions except C6. Seven people responded to some parts of this question while six responded to others.

C.2 Question by Question Summary of Ceramics Section

C1 asks the respondent to estimate the percentage of new cars fifteen years hence with three unconventional types of ceramic engine and with conventional engines with either few ceramic components or many ceramic components.

Conventional engines with a few ceramic components were estimated to make up about 50% of the total while conventional engines with many ceramic components were estimated to be in the 10% range. Two of the three unconventional engines, (ceramic-based gas turbine and ceramic-based external combustion) are estimated at less than 1% while ceramic-based Diesel is estimated at about 1%. Since there was no enforced normalization of estimates the responses more accurately give relative values than absolute ones.

C2 asks for an importance rating of three factors in facilitating a breakthrough in the use of ceramics in auto engines. The factors are, a reduced cost for the manufactured ceramic, improved processing resulting in reproducible reliability in the ceramic and a new material or mix of materials with superior properties.

"Improved processing resulting in reproducible reliability" unanimously received the highest rating possible, (very important). Responses for "Reduced costs" centered between (very important) and (considerable importance) while those for "New material" centered between (moderate importance) and (considerable importance).

C3 asks when ceramic engines (an engine containing 8kg or more of ceramic) will appear on more than 20% of new cars.

The median of the third round responses to this question lay between, "between 10 and 15 years from now" and "not within 15 years", but closer to the latter. No respondent chose ,"never". The response to this question was consistent with the response to question C1.

C4 asks when the cost of high performance ceramics will drop to half its current value.

The third round responses are centered between, "between 5 and 10 years from now", and "between 10 and 15 years from now". This is consistent with an estimate of about 10 years.

C5 asks when electrotechnologies will play a major role in the pre-sintering part of production and when microwave heating will play a major role in sintering.

The responses are consistent with an estimate of about six years for the former and about eight years for the latter.

C6 asks for the percentage (by tonnage) of the ceramic market held by a number of ceramic types 15 years hence.

The share for Al_2O_3 was estimated at between 25 and 50%. The share levels for SiC and for Si_3N_4 were each estimated between 10 and 25%. The share levels for each of four other types, (TiB_2, WC, PSZ and BN) were estimated at less than 10%.

C7(a non-Delphi question) asks which of three industries (automotive, aerospace or electronics) will experience the largest absolute increase in ceramic use in the next decade.

Six out of eight respondents chose the automotive industry while two chose the electronics industry.

C.3 Plastics Questions - Overview

The plastics section of the questionnaire consists of five questions all of the usual Delphi type and all repeated for three rounds. Five participants responded to these questions. There was good agreement on the third round by which time at least four of the five respondents gave the same answers.

C.4 Question by Question Summary of Plastics Section

P1 asks when plastic will become the predominant body material in 50% of new cars. The unanimous third round response was, "from 10 to 15 years from now".

P2 asks the respondents to estimate the electrical energy required to produce plastic car-body components as a fraction of that required by metals they will replace.

Four out of the five participants chose, "between one half and three quarters" as their third round answer. One chose, "the same or more".

P3 asks when plastics will displace 50% of the glass currently used for food and beverage containers.

Four of the five participants chose, "from 6 to 10 years" as their third round response while one chose, "from 10 to 15 years".

P4 asks when under-the-hood use of plastics in autos would double its current level.

Four of the five respondents chose, "from 6 to 10 years from now as their third round response while one chose, "from 10 to 15 years from now".

P5 asks when intrinsically conductive polymers will find application as bulk electric conductors.

The unanimous third round choice was, "not until after 15 years from now". Though this is a fairly negative response the participants were also offered, "never" as a possible answer

but no one made it their final choice.

C.5 Metals Section - Overview

The metals section contains three questions one of which contains three parts. All of the questions were of the usual Delphi type and were repeated for three rounds. Seven participants responded to these questions and there was a good convergence of answers by the end of the third round.

C.6 Question by Question Summary of Metals Section

M1 asks the respondent to consider Ontario steel production as a fraction of the gross provincial product and to estimate what percentage of its current value it will have in 15 years.

Six of the seven participants chose, "60 to 80%". One chose, "40 to 60%".

M2 asks when a stated Alcan target, (i.e. to replace steel as the dominant structural material in cars, trucks and trains with metal-polymer laminates and aluminum alloys) is likely to be achieved.

Six of seven participants chose, "from 10 to 15 years from now" while one chose, "from 6 to 10 years from now".

M3 asks the respondent to compare future and current tonnages of three specific metals mined in Ontario. The future being considered is fifteen years hence, while the metals are zinc, nickel and copper.

Respondents unanimously chose, "essentially the same as" to compare the levels for zinc. Five out of seven chose, "somewhat less than" to compare the future level with the present level for nickel while two chose, "essentially the same as". Six chose, "somewhat less than "to compare the future level with the present level for copper while one chose, "essentially the same as".

C.7 Electrolytic Materials Questions - Overview

The electrolytic materials section of the questionnaire consists of four questions. The first two of these questions are of the usual Delphi form and were repeated for three rounds. Question E1 has four parts while question E2 has two parts. Questions E3 and E4 are non-Delphi questions and were completed after the first round.

Five people responded to the question in this section of the questionnaire.

C.8 Question by Question Summary of Electrolytic Materials Section

E1 consists of four parts, all relevant to fuel cell progress. Question E1(a) asks when fuel cells will be a viable alternative to combustion turbines in utility applications. Question E1(b) asks when fuel cells will become a viable alternative, (in the planning process) to large nuclear or fossil stations in Ontario. Question E1(c) asks when fuel cells will make cogeneration a significant factor in Ontario's energy scene.

The median position of the third round responses for each of these questions was, "between 10 and 15 years from now". In each case the replies of the five participants were spread over three adjacent possible responses. The lack of consensus among experts is good grounds for caution in the use of these predictions.

Question E1(d) asks when fuel cells will become a viable option for the power source of personal vehicles. Once again the replies are spread over three adjacent possible responses. The median response in this case is, "not until after 15 years from now".

E2 consists of two parts, both relevant to battery technology. Question E2(a) asks when batteries will become a competitive means for bulk storage of electricity.

Four out of the five participants chose, "not until after 15 years from now".

Question E2(b) asks when advances in battery technology will make electric vehicles for personal transportation competitive with conventional vehicles.

The median response on the third round was, "between 10 and 15 years from now". The five replies were spread over three adjacent possible responses indicating little consensus on this question.

E3 is not a Delphi question but asks the respondent to comment on the following paragraph.

"A recent U.S. study predicts that phosphoric acid fuel cells will be economically viable as peaking units by 1995. Some experts predict that the phosphoric acid fuel cells will then eventually be replaced by molten carbonate of solid oxide units."

All of the comments were consistent with solid oxide having the potential to replace the other two types as the top contender for practical application.

E4 is not a Delphi question and was terminated after one round. It asks what type of power source will power the first electric vehicle to seriously challenge the conventional automobile.

Three of the five responded "sodium-sulphur battery". One responded, "solid oxide fuel cell but not until after the year 2000" and one responded "superconducting energy storage device".

C.9 Superconducting Questions - Overview

Three of the four questions in this section are of the usual Delphi type and were repeated for three rounds. The fourth question which is a non-Delphi question was completed after the first round.

Eleven participants responded to the questions in this section.

C.10 Question by Question Summary of Superconducting Materials Section

S1 asks when room temperature superconductivity at atmospheric pressure will be achieved.

Eight of the eleven respondents on the third round chose, "from 3 to 6 years from now", two chose, "within 3 years" and one chose, "from 6 to 10 years from now".

S2 asks for a rating of the relative significance of problems in the current carrying capacity and in the mechanical properties of the material as impediments to practical application.

The distribution of third round responses is shown in the table below.

Significance of Problem	Current Carrying Capacity	Mechanical Properties
No Problem	0	0
An Easily Overcome Obstacle	1	0
Significant but Tractable	10	9
A Limiting Factor	0	2
An Insurmountable Obstacle	0	0

S3 asks when various applications will materialize. The applications are (A) new transmission lines - including underground lines, (B) diurnal energy storage, (C) fault limiters, phase shifters and other control devices and (D) superconducting generators.

The third round responses are shown in the table below.

Time Frame	(A)	(B)	(C)	(D)
Within 5 years	0	0	0	0
Between 5 and 10 years from now	3	1	2	3
Between 10 and 15 years from now	0	10	9	8
Not until after 15 years from now	8	0	0	0
Never	0	0	0	0

Though there was confusion on this question as to exactly what constitutes a transmission line application, comments by participants reveal that the disagreement on this topic is real and accurately reflects a lack of consensus.

S4 is a non-Delphi question and asks, "If durable, high current density, high transition temperature superconductors can be produced relatively cheaply will there be any significant effect on the market for electricity?".

Seven respondents said, "yes" ,three said, "I don't know" and one said, "no". The most frequently mentioned ways in which it would alter the market were load shifting through energy storage and making electricity more attractive for use in transportation. These two were mentioned with about equal frequency.

C.11 General Questions - Overview

This section could as well have been called the miscellaneous section. It contains two Delphi questions, one on fusion and one on the influence of new materials on electricity consumption. As well it contains two non-Delphi questions, both on areas of materials research appropriate for consideration in this laboratory.

Twenty-five participants answered most of this section of the questionnaire.

C.12 Question by Question Summary of General Section

G1 asks when fusion will become a serious planning option for electricity generation. On the third round 22 of the 25 respondents chose, "not until after 15 years from now". Two chose, "between 10 and 15 years from now", and one chose, "between 5 and 10 years from now". Interestingly no one chose, "never".

G2 concerns new materials likely to replace traditional materials over the next 15 years. The respondent is asked about the amount of electricity required to manufacture these materials as compared to the amount required to manufacture the materials they replace.

The third round reply of 19 of the 24 respondents to this question was that the new materials will consume between 5 and 25% more electrical energy than do the materials they replace. The five other responses were spread across three other possible categories.

G3 presents a list of 27 advanced-materials areas previously suggested by Research Division personnel as being deserving of attention by the Division. The respondent is asked to augment the list if he or she knows of other such areas that are appropriate.

Eleven new areas were suggested but none were mentioned by more than one respondent.

G4 the participants were asked to identify any of the areas on the G3 list that they felt were particularly meritorious. Five of the 27 areas were mentioned by more than two respondents. These are listed below followed by the number of mentions in brackets.

- Superconducting ceramics (12)
- Ceramic composites for high temperature applications (4)

- High density ceramics for high temperature high exchangers, bearings and nozzles (3)
- Conducting ceramics for electrochemical reactors (3)
- Conductive polymers (3)

Nine areas got two mentions, three areas got one mention and ten areas got no mention. It is interesting to note that four of the five areas listed above have the word, "ceramic" in them. Only one area containing that word, "Ceramic coatings and surface modification for wear, corrosion and heat resistance", got less than three mentions. It received two.

APPENDIX D

QUESTIONNAIRE WITH THIRD ROUND RESULTS AND COMMENTS

This Appendix presents a complete summary of the final round answers for all the questions. For each of the question, the number of answers for each of the choices is tallied and is shown beside the choice. In addition, all the comments made throughout the Delphi exercise are also listed. The comments are shown in italics with the first round comments being marked by a "o", the second round comments by a "+" and the third round comments by a "*".

C1.

Several types of ceramic engines have been evaluated in prototype form. These include a ceramic gas turbine, a ceramic-based adiabatic turbo-compound diesel, and a ceramic-based external combustion (Stirling cycle) engine. Of course, the automobile engine may remain essentially the same type as it is now with or without a substantial increase in the number of ceramic components.

Please mark the boxes below which most appropriately express your estimate of the number of new vehicles fifteen years hence with the specified types of engine.

	0 - 1 %	1 - 10%	10 - 25%	25 - 50%	Over 50%
Ceramic-Based Gas Turbine	(8)	( )	( )	( )	( )
Ceramic-Based Diesel	(4)	(4)	( )	( )	( )
Ceramic-Based External Combustion	(8)	( )	( )	( )	( )
Present Type with Few Ceramic Components	( )	( )	( )	(6)	(2)
Present Type with Many Ceramic Components	( )	(5)	(3)	( )	( )

o *The most likely scenarios are those in which ceramic components replace metal ones in high wear, high temperature applications.*

o *The best chance for a totally ceramic engine is in the diesel area.*

\+ *Since much effort is put on ceramics and many engines contain ceramic parts now, at least 50% will contain a few ceramic parts in 15 years.*

C2.

If a ceramic engine[1] achieves significant penetration of the passenger vehicle market, one or more of the factors listed in C2 (a) to C2 (c) will have contributed. Please rate the likely importance of each of these factors.

C2 (a).

A reduced cost for the manufactured ceramic.

( ) little or no importance
( ) some importance
(1) moderate importance
(5) considerable importance
(2) very important

+ *The advantages of ceramic engines are in performance not costs. They are significant enough to override costs*

+ *The ceramic engine has already been demonstrated, the "very important" factor limiting market penetration is the cost of producing high reliability components.*

---

1. Ceramic engine here means an engine type using more than 8 kg of ceramic/engine (ie. not just a conventional engine with ceramic cylinder liners, piston caps etc.).

C2 (b).

Improved processing resulting in a reproducible reliability in the ceramic.

( ) little or no importance
( ) some importance
( ) moderate importance
( ) considerable importance
(8) very important

o *Until reliability is achieved, ceramics will not play a major part in automotive technology.*

C2 (c).

A new material or mix of materials with superior properties.

( ) little or no importance
(1) some importance
(1) moderate importance
(4) considerable importance
(2) very important

o *Research in Ceramics Engine technology is leaning towards composite materials rather than monolithics.*

+ *Ceramic composites will be required and this is a "very important" and necessary development.*

+ *Materials with the required properties already exist. It is the technology to produce the required reliability in a cost competitive way which is absent.*

C3.

Please check the most appropriate ending to the following sentence. Ceramic engines[2] will be included on 20% or more of new cars _____.

( ) within 5 years
( ) between 5 and 10 years from now
(2) between 10 and 15 years from now
(6) not until after 15 years from now
( ) never

\+ *This is very dependent on continued or increased government support to industrial programs. The time frame is also dependent on the degree of acceptance by automotive companies.*

---

2. Ceramic engine here means an engine type using more than 8 kg of ceramic/engine (ie, not just a conventional engine with ceramic cylinder liners, piston caps, etc.)

C4.

The present cost of high performance ceramics is a limiting factor in its use. This cost would be expected to drop as processes becomes standardized and production increases. Please check the most appropriate ending to the following sentence.

This cost will drop to half its current level _____.

( ) within 5 years
(4) between 5 and 10 years from now
(4) between 10 and 15 years from now
( ) not until after 15 years from now
( ) never

C5.

Several innovative methods including microwave heating and plasma technologies are currently being explored for use in ceramic production. Please check the most appropriate ending for each of the following sentences.

C5(a).

Electrotechnologies will start to play a major role in the pre-sintering part of the production process _____.

(6) within 5 years
(2) between 5 and 10 years from now
( ) between 10 and 15 years from now
( ) not until after 15 years from now
( ) never

+ *For drying stages, electrotechnologies will have immediate applications, but powder preparation is still in the future.*

+ *Electrotechnologies will start to play a major role in pre-sintering of traditional ceramics in the next 3 to 10 years. I expect its use for advanced ceramics will come after that (ie, 10 to 15 years).*

C5 (b).

Microwave heating will start to play a major role in ceramic sintering _____.

(4) within 5 years
(4) between 5 and 10 years from now
( ) between 10 and 15 years from now
( ) not until after 15 years from now
( ) never

o *Assuming production process - experimental sintering is already feasible.*

C6.

Please estimate the likely percentage of the ceramic market (by tonnage) held by each of the ceramic types below in fifteen years.

	0 - 1 %	1 - 10%	10 - 25%	25 - 50%	Over 50%
Si C	( )	( )	(7)	( )	( )
$Si_3 N_4$	( )	( )	(7)	( )	( )
$Al_2 O_3$	( )	( )	( )	(6)	(1)
$Ti B_2$	( )	(6)	( )	( )	( )
W C	( )	(6)	( )	( )	( )
PSZ (partially stabilized zirconia)	( )	(7)	( )	( )	( )
B N	(3)	(3)	( )	( )	( )

+ *SiC has its problems at high temperature and ambient atmosphere - its use will be limited to specific applications.*

+ *WC has applications in cutting tools and wear components.*

* *The use of Al_2O_3 as an advanced ceramic will depend on developments made in the area of reinforcing fibers.*

Note: One participant did not respond for Ti B_2, WC and BN and one did not respond for this question at all.

C7. (Non-Delphi Question)

Please check the most appropriate ending to the sentence below.

The largest absolute increase in ceramic use in the next decade will be in _____.

(6) the automotive industry
( ) the aerospace industry
(2) the electronic industry
( ) other (please specify)

P1.

General Motors currently produces its Fiero line of cars with plastic bodies (at least external panels). Several recent advances in plastics manufacturing seem to be making plastic more competitive in this application. Please check the most appropriate ending to the sentence.

Plastic will become the predominant body material in 50% of new cars _____.

( ) within 3 years
( ) from 3 to 6 years from now
( ) from 6 and 10 years from now
(5) from 10 to 15 years from now
( ) not more than 15 years if ever

P2.

Some electrical energy is used in producing plastic car-body components and some electrical energy is used in producing the metal parts they are replacing. Please check the phrase that most appropriately fills the blank in the following sentence.

The electrical energy required to produce the plastic component will be _____ required for the metal component it replaces.

( ) less than one quarter of that
( ) between one quarter and one half of that
(4) between one half and three quarters of that
( ) between three quarters and the same amount as that
(1) the same or more than that

\+ *New "superplastics" materials can be cold formed on equipment used for sheet steelmaking. No heat is required to vulcanize or cure the plastics. The total energy required to produce plastics is much less than for metals.*

P3.

Please check the ending that most appropriately completes the following sentence.

Plastics will displace 50% of the glass currently used for food beverage containers _____.

( ) within 3 years
( ) from 3 to 6 years from now
(4) from 6 to 10 years from now
(1) from 10 to 15 years from now
( ) not for 15 years if ever

\+ *Never for malt, scotch and beer!*

P4.

New temperature-resistant plastics are expected to increase the under-the-hood[3] use of plastics in autos. Please check the ending most appropriate to the sentence below.

Under-the-hood use of plastics will double its current level _____.

( ) within 3 years
( ) from 3 to 6 years from now
(4) from 6 to 10 years from now
(1) from 10 to 15 years from now
( ) not for 15 years if ever

+ *In the last decade, the annual growth rate of plastic usage in domestic cars was about 2.9%. The plastic content of a domestic car went from 4.3% to 6.8%. In the coming decade, competing advances in the steel industry and the public attitudes towards the safety of plastics at high temperatures will slow its growth.*

+ *Automakers are studying plastics for belt pulleys, various gear drives, some transmission components and high temperature plastic pistons.*

---

3. Under-the-hood means engine, radiator, transmission, etc.

P5.

Please check the ending that most appropriately completes the following sentence. Intrinsically, conductive polymers will find application as bulk electric conductors _____.

( ) within 5 years
( ) from 5 to 10 years from now
( ) from 10 to 15 years from now
(5) not until after 15 years from now
( ) never

\+ *Recent advances in superconductivity will accelerate the rate of application of conductive polymers as bulk electric conductors.*

M1.

Please check the most appropriate phrase to fill the blank in the following sentence.

In fifteen years, Ontario steel production expressed as a fraction of the gross provincial product will be _____ its current value.

( ) the same or greater than
( ) 80 to 100% of
(6) 60 to 80% of
(1) 40 to 60% of
( ) less than 40% of

o *Ontario is good in steelmaking. There will be little change in absolute terms - a small decline percentagewise.*

o *Competition from other materials though strong. will be resisted by steelmakers. and raw materials costs for competition will rise more sharply than for steel.*

+ *Ontario's steelmaking expertise will prevent much of a decline.*

+ *Steel can be replaced in automobiles and it is likely to happen in a significant way - service sector growth relative to manufacturing.*

• *Cars imported to Canada from off shore represent a missed opportunity to use Canadian steel.*

M2.

Alcan recently stated that it was determined to replace steel as the dominant structural material in cars, trucks, and trains with metal-polymer laminates and with aluminum alloys. Please check the most appropriate ending to the following sentence.

One might realistically expect the above target to be achieved _____.

( ) within 3 years
( ) from 3 to 6 years from now
(1) from 6 to 10 years from now
(6) from 10 to 15 years from now
( ) not for 15 years if ever

o *Steel is cheap to buy and easy to shape - Designers have a lot to learn about high performance materials. A change in public perception about the relative importance of the first cost versus life cycle must occur.*

o *Automotive companies prefer polymers and ceramics. Rail companies cannot afford Aluminium and composites.*

\+ *Aluminium and metal/polymer laminates may never be cost effective for land transportation.*

\+ *People enjoy replacing cars every 5 years or so, why make them durable.*

\+ *Aluminium alloys have yet to prove as versatile as steel in these applications.*

\+ *Some replacement will occur, but steel will dominate in 15 years.*

M3.

Though there have been some yearly fluctuations, there is an apparent trend toward lower tonnages of nickel, copper, and zinc being mined in Ontario in recent years. Please check the appropriate phrases to fill in the blanks in the following sentences.

M3 (a).

Fifteen years hence, the tonnage of zinc mined in Ontario will be _____ its current level.

( ) substantially greater than
( ) somewhat greater than
(7) essentially the same as
( ) somewhat less than
( ) substantially less than

o *Zinc has a very interesting electrochemical behavior and is currently underutilized. Ontario is well placed to participate in an increased world market.*

o *Third world competition is an important factor here.*

\+ *Zinc base precision castings used currently in the automotive industry are being replaced by plastics and other materials resulting in a consumption in this sector.*

M3 (b).

Fifteen years hence the tonnage of nickel mined in Ontario will be _____ its current level.

( ) substantially greater than
( ) somewhat greater than
(2) essentially the same as
(5) somewhat less than
( ) substantially less than

o *Hard rock mining of Sulphide deposits is an inherently high cost business.*

o *Third world competition is an important factor here.*

+ *Although the market for Nickel will increase, economic deposits in Ontario will be worked out.*

+ *Production may be cut to meet SO_2 standards.*

+ *Substitution of robots in underground mining will return competitiveness of industry.*

• *Major Nickel producers in Ontario have expressed the desire to expand production within the near future, if SO_2 criteria can be satisfied.*

M3 (c).

Fifteen years hence the tonnage of copper mined in Ontario will be _____ its current level.

( ) substantially greater than
( ) somewhat greater than
(1) essentially the same as
(6) somewhat less than
( ) substantially less than

o *Third world competition is an important factor here.*

+ *Except in time of political crisis etc. we can't compete with Zambia, Chile and others.*

+ *Fiber optics and other development in data transmission will cause a major decline in copper use.*

• *I disagree with the above comment. It is power applications where the real tonnage goes and Copper will remain technically preferable here.*

• *Even plumbing which was a big market for Copper is turning to plastics.*

E1.

Materials advances have resulted in substantial recent progress in solid oxide fuel cells. These has also been progress both in phosphoric-acid and in molten-carbonate fuel cells. Please check the most appropriate ending to each of the sentences below.

E1 (a).

Fuel cells will be a viable alternative to combustion turbines in utility applications _____.

( ) within 5 years
(2) between 5 and 10 years from now
(2) between 10 and 15 years from now
(1) not until after 15 years from now
( ) never

o *Cost and unfamiliarity with the technology were deterrents to utility acceptance of International Fuel Cells initial 11 MW PAFC commercial offering.*

+ *Westinghouse is still pushing forward on their Solid Oxide Fuel Cell and have manufactured cells on a batch basis. Their timetable for commercial offerings is the early 90's - Multi megawatt units by the later 90's.*

+ *Utilities may not be able to run combustion turbine units in populated areas because of environmental and noise problems.*

+ *Solid Oxide Fuel Cells are 5 to 10 years behind Phosphoric Acid Fuel Cells.*

+ *Looking at North American activities at present, Fuel cells are far from commercialization. But activities in Japan give cause to more optimism.*

• *Most new fuel cells (eg. SOFC) are still in the small size (watts or kW not MW) range.*

E1 (b).

Fuel cells will become a viable alternative to the addition of large fossil or nuclear stations in Ontario (Consider the choices below to be the times at which they would become a viable planning option - not necessarily the times they would be added to the system.) _____.

( ) within 5 years
(!) between 5 and 10 years from now
(3) between 10 and 15 years from now
(1) not until after 15 years from now
( ) never

o *Development of the solid oxide fuel cell (SOFC) technology at Westinghouse and Argonne National Laboratories may demonstrate the necessary economies, fuel flexibility and reliability, in this time frame.*

o *11 MW PAFC demonstrations should be essentially completed in this time frame.*

+ *The largest solid oxide fuel cell tested at Argonne National Laboratories is three orders of magnitude smaller than at Westinghouse.*

+ *Utilities will only plan fuel cell use after a long life time has been demonstrated.*

E1 (c).

Fuel cells will make cogeneration a significant factor in Ontario's energy scene _____.

( ) within 5 years
(1) between 5 and 10 years from now
(3) between 10 and 15 years from now
(1) not until after 15 years from now
( ) never

o *Political and environmental concerns will dictate large scale applications. Small scale (distribution side or remote areas) applications possible sooner.*

+ *There may be a demo or two, but this is not a significant factor.*

+ *Westinghouse offerings are first targeted on small commercial units in the next 5 to 10 years. The impact on the system may lag somewhat but by 10 years, expect it to be significant.*

• *International Fuel Cells, having learned from the joint UTC/GRI 40kW demonstration program, is currently developing and marketing a marketing a 200kW PAFC unit for this type of application with considerably more success than with their 11MW plant.*

E1 (d).

Fuel cells will become a viable option for the power source of personal transportation vehicles _____.

( ) within 5 years
( ) between 5 and 10 years from now
(1) between 10 and 15 years from now
(3) not until after 15 years from now
(1) never

o *Alkaline fuel cells being developed by Astris Technologies for this purpose.*

o *Ballard Technologies Inc. is developing SPE fuel cells for similar applications.*

o *Argonne Labs monolithic SOFC holds great promise, but requires significant development work.*

o *Not as they are known today. Different types of fuel cells may emerge for this application.*

+ *Perhaps in conjunction with a battery.*

+ *Superconductors may revolutionize transport as we know it.*

+ *Alkaline fuel cells require pure (electrolytic) H_2 and CO_2 free air for long life. It is doubtful that it will be attractive for another 40 years. Any other fuel cell requires a reformer on board - an impractical solution.*

+ *The development cycle is probably similar to that for battery technologies for transportation vehicles.*

• *With advances in materials science and the revolutionary developments in superconductors, fuel cells could become viable as power sources for small vehicles.*

E2.

Many recent materials advances have implications for battery technology which is in any case improving steadily. Please check the most appropriate ending to each of the following sentences.

E2 (a).

Batteries will become a competitive means for the bulk storage of electricity (daily load leveling etc.) _____.

( ) within 5 years
( ) between 5 and 10 years from now
(4) between 10 and 15 years from now
(1) not until after 15 years from now
( ) never

o *Breakthroughs in superconductor technology will divert research efforts to superconducting storage devices.*

+ *I don't see there being any energy storage facility (commercial) within 15 years. Utilities such as Ontario Hydro will be doing more to shift loads before building a energy storage device.*

E2 (b).

Advances in battery technology will make electric vehicles for personal transportation competitive with conventional vehicles _____.

( ) within 5 years
(1) between 5 and 10 years from now
(3) between 10 and 15 years from now
(1) not until after 15 years from now
( ) never

o *Only when oil and gasoline prices start climbing again, will interest in battery technology for electric vehicles really pick up.*

+ *Economic and political environments will determine events between 5 and 10 years from now.*

+ *The decline in oil prices is probably temporary and we will see $30 per barrel sometime in 1988.*

+ *Fuel prices must rise again and batteries must be proven to be durable, have long cycling lives and be affordable. I doubt that this will happen within 15 years.*

+ *Superconductors may revolutionize transport as we know it.*

E3. (Non-Delphi Question)

A recent US study predicts that phosphoric acid fuel cells will be economically viable as peaking units by 1995. Some experts predict that the phosphoric acid fuel cells will then eventually be replaced by molten carbonate or solid oxide units.

Please comment on these predictions (one to four sentences).

- *Molten Carbonate fuel cells are unlikely to make much impact. Solid oxide units may quickly replace phosphoric acid cells. Phosphoric acid will not be used long for peaking - solid oxide will do better in the development race.*

- *Phosphoric acid fuel cells are more advanced than the other two concepts, but the performance of all three can be improved. Depending on further R&D, any of the three might be used for peaking.*

- *Phosphoric acid unit viability will depend on the success of EPRI's efforts to organize three consortia to proceed with three demonstrations of 11 MW units. High capital costs and lack of utility familiarity with the technology deter current efforts. Developments in solid oxide cells along with slow implementation of phosphoric acid cells could result in utilities holding off and leap frogging molten carbonate to solid oxide.*

- *Ceramic fuel cells are probably the better bet but high transition super conductors may displace fuel cells as a peaking option.*

E4. (Non-Delphi Question)

Please check the most appropriate ending to the sentence below and justify your choice in one or two sentences.

The first electric vehicle to seriously challenge the conventional automobile will have as a power source a _____.

( ) Zinc Halogen battery
(3) Sodium Sulphur battery
( ) Nickel Cadmium battery
( ) Lead Acid battery
( ) Aluminum air battery
(1) Solid Oxide fuel cell
(1) Other (please specify)
Superconducting motor and battery

S1.

Please check the most appropriate ending to the sentence below.

Room temperature superconductivity at atmospheric pressure will be achieved _____.

(2) within 3 years
(8) from 3 to 6 years from now
(1) from 6 to 10 years from now
( ) from 10 to 15 years from now
( ) not for 15 years if ever

o *Although the increase in the critical temperature has been dramatic over the past year, the last 50 degrees or so will be much more difficult to achieve.*

\+ *Given that the mechanism is not yet understood, there is no evidence that the pace of increases will slow and resources dedicated to this are increasing.*

\+ *Once a reasonable theory has been worked out, it may not be that difficult to modify the structure of the compound to yield the right conditions.*

\+ *There are many permutations of elements and preparation techniques which should permit the achievement of room temperature superconductivity by 1991.*

\+ *A different material will be required to achieve this.*

* *Possibly in the laboratory, but unlikely for practical power conductors.*

* *This depends on whether we mean bulk superconductivity or superconductivity in a few grains. Materials superconductive at 280°K should be available in three years, but its practical application is another matter.*

S2.

Though the recently discovered ceramic superconductors are scientifically very exciting and will almost certainly be used in Josephson junction applications, there may be significant barriers to some of their other potential applications.

Please check the ending most appropriate to each of the following sentences.

S2 (a).

Current carrying capacity will prove to be _____.

( ) no problem
(1) an easily overcome obstacle
(10) a significant but tractable problem
( ) a limiting factor
( ) an insurmountable obstacle

o *The current carrying capacity appears to be adequate for most applications at this time, except perhaps for integrated circuit work.*

\+ *In a matter of 2 to 3 months, the current carrying capacity has increased by 2 to 3 orders of magnitude. A further increase of only 1 order of magnitude is needed. This might come through a better process of making the ceramics.*

\+ *Given the relative infancy of the field, all problems have the potential of being easy or difficult. IBM's recent advancements in current capacity were clearly unexpected.*

* *The current carrying capacity seems to be a function of crystal structure. So far, the push has been to higher transition temperatures, with relatively little effort to exploring crystal structure.*

S2 (b).

The mechanical properties of the material (brittleness, fragility, etc.) will prove to be _____.

( ) no problem
( ) an easily overcome obstacle
(9) a significant but tractable problem
(2) a limiting factor
( ) an insurmountable obstacle

o *A number of approaches such as plasma spray coating may hold the answer. Just as HTSC's are an unexpected breakthrough, we might expect other directions in their utilization.*

\+ *Mechanical properties of ceramics are always a limiting factor for some applications.*

\+ *For power cable applications, a truly flexible conductor is required.*

\+ *Fabricating wire and coil with the proper electrical properties may prove difficult, especially if a single crystal is required to yield a pure superconducting phase.*

• *To be economically competitive, a flexible cable which can be pulled into pipes or trenches several hundred meters long, with bends, is essential. Cable designers or operators prefer systems with the least number of joints.*

• *They will be a limiting factor in some applications.*

• *The techniques used for making semiconductor devices may be mated with those used in the production of ceramics to provide new ways of carrying current.*

S3.

There are many potential applications of high transition temperature super conductors. Please check the most appropriate ending to each of the following sentences.

S3 (a).

Superconductors will be cost effective for most new transmission lines _____.
(Editor's Note: "Transmission lines" is meant to include underground transmission)

( ) within 5 years
(3) between 5 and 10 years from now
( ) between 10 and 15 years from now
(8) not until after 15 years from now
( ) never

+ *In biotechnology, the first products were on the market within less than a decade from the fundamental breakthrough. This quick progress was made in the face of strong opposition to genetic engineering research.*

+ *Five to 10 years should be good timing for underground cables.*

• *A 4% transmission loss means a $ loss of about $200 million per year. Superconducting lines would end this loss and perhaps have other advantages (lower voltage etc.) offsetting cooling costs and making them cost effective soon.*

S3 (b).

Superconducting coils will become cost effective for storing electrical energy (on a daily basis) _____.

( ) within 5 years
(1) between 5 and 10 years from now
(10) between 10 and 15 years from now
( ) not until after 15 years from now
( ) never

+ *Coils are being fabricated at the present time. The difficulty is obtaining high critical current. Once this problem is solved, S.C. coils will be used right away. I have to believe that higher critical currents are just around the corner.*

+ *There are already 1 or 2 examples of superconducting storage devices of some size. Since the technology of storage is well understood, the only limitation will be the material itself. Within 5 to 10 years, problems with the material will be solved.*

• *There are many recent discussions in the literature of 5000 MW devices being considered by utilities with a time horizon of 5 to 10 years.*

S3 (c).

Superconducting components will be used in fault limiters, phase shifter, and in similar control devices _____.

( ) within 5 years
(2) between 5 and 10 years from now
(9) between 10 and 15 years from now
( ) not until after 15 years from now
( ) never

+ *Understanding of the devices exist. We are only waiting for the material.*

• *These devices are much smaller than superconducting storage devices and therefore should be available earlier.*

S3 (d).

Superconducting generators will become cost effective _____.

( ) within 5 years
(3) between 5 and 10 years from now
(8) between 10 and 15 years from now
( ) not until after 15 years from now
( ) never

o *Superconducting generators are already cost effective with Helium cooling and conventional superconductors. They should be cost effective at liquid Nitrogen temperatures even if the new HTSC materials are more expensive than the more conventional SC materials.*

+ *Superconducting generators will become cost effective on our system gradually, as the old generators near design life limitations.*

+ *The difficulty at the present time is the attainment of high critical currents.*

• *The development of generators with superconducting rotors is continuing using conventional superconductors. These may be cost effective now in special situations. A generator with superconducting rotor for Ontario may be further in the future and one with a superconducting stator and rotor may be much further in the future.*

• *For new facilities, 5 to 10 years is appropriate, but for existing facilities, the change will occur at replacement time.*

S4. (Non-Delphi Question)

If durable, high current capacity, high transition temperature superconductors can be produced relatively cheaply will there be any significant effect on the market for electricity in Ontario?

(If your answer is yes, please include an explanatory sentence.)

(1) no
(3) don't know
(7) yes

- *Resistance losses will be reduced for motor and magnet applications possibly reducing electricity use. Convenient methods of storing electricity could in time shift industrial operations from fossil fuel to electrical*
- *Although electricity will be used more efficiently, new use of electricity will be opened. All the transportation industry and the automobile industry will tend to use electricity driven vehicles. Motors will be smaller and more efficient*
- *Transportation*
- *Small energy storage devices*
- *Possibility of maglev devices, energy storage etc*
- *Impact on load shifting, reserve margins, reliability criteria etc.*
- *New applications and efficiency of use*

G1.

Fusion reactors may one day provide a competitive way of generating electricity. Many would say that their realization is too far away and too uncertain for them to be a serious planning option yet. Please check the most appropriate way to fill in the blank in the sentence below.

It will, _____, become obvious that fusion will eventually provide a cost competitive means of generating electricity.

( ) within 5 years
(1) between 5 and 10 years from now
(2) between 10 and 15 years from now
(22) not until after 15 years from now
( ) never

o *Although fusion itself is quite simple, the equipment and infrastructure needed to make a business of it is extremely complicated and of high capital cost.*

o *Results at Princeton have been encouraging but development of confidence and scaling up to commercial size (prototype) will be time consuming.*

+ *Work planned or under way (General Atomic, Los Alamos etc) should result in a Tritium burning reactor giving engineering data for commercial units in 10-15 years.*

+ *This question refers to assessment, not implementation.*

+ *The problems with pollution of the environment with Fusion are far worse than with current technology.*

• *A number of facilities such as NET, TIBUR and other engineering test reactors planned for the 1990's are all tritium burning and should provide data by the end of the century on the usefulness of fusion as a utility power source.*

G2.

Many traditional materials seem likely to be replaced by advanced ceramics, plastics, composites or new metallic alloys over the next 15 years. The picture for electricity use is complicated by the fact that some of the new materials will use more electricity than the materials replaced and some will use less. Please check the phrase most appropriate to fill in the blank in the following sentence.

Overall, the electrical energy required in the manufacture of the new materials will be _____ that required for the materials they replace.

(1) substantially more than (greater than 125%)
(19) more than (105 to 125%)
(2) about the same as
(2) less than (75 to 95%)
( ) substantially less than (less than 75%)

o *But the electricity use may not be in Ontario (eg. Al. SiC. Si_3N_4)*

o *Traditional materials mostly use fossil energy.*

\+ *Plastics will probably dominate. These use little electric energy (compare to Aluminium)*

\+ *New "superplastics" materials can be cold formed on equipment used for sheet steelmaking. No heat is required to vulcanize or cure the plastics. The total energy required to produce plastics is much less for metals.*

\+ *The overall energy budget for replacement materials should be reduced to 30 to 60% of current materials. but the "electrical component" will increase substantially.*

\+ *Plastics and composites generally require less electrical energy throughout from basic materials to finished components than steel and other metals. It is not believed that ceramics and new metallic alloys will use more than traditional materials.*

- *With more efficient heating equipment, the use of novel electrotechnologies such as IR and microwaves, advanced materials will on average not use more energy than traditional materials.*

- *The electrical component can vary substantially among traditional materials. Note also that electrochemical routes are being investigated for synthesis.*

- *Plastics will require less electrical energy but ceramics and Aluminium will require more.*

G3. (Non-Delphi Question)

Listed below are a number of advanced materials areas which have been suggested as deserving of attention by the Research Division. If you can augment this list, please do so including a sentence or two explaining the merit of your suggestion.

- Al - Li alloys for light strong structures.
- Li for batteries.
- High strength, heat tolerant alloys for tubes in super critical boilers.
- Isotope depleted zirconium for pressure tubes and fuel bundles.
- Shape memory alloys for tube repairs and heat-sensitive switches.
- Glassy metals for heat exchangers and transformers.
- Directionally solidified alloys for high-temperature stability of structural components.
- Super alloys and duplex stainless steels for flue gas desulphurization equipment.
- Metal matrix composites for components with particular strength or durability requirements.
- High density ceramics for high temperature heat exchangers, bearings and nozzles.
- Ceramic coatings and surface modifications for wear, corrosion, and heat resistance.
- Novel inorganic coatings for buried pipelines and cables.
- Temperature tolerant polymers for heat exchangers.
- Fibreglass reinforced plastics for components requiring corrosion resistance or lightweight strength. (The design constraints, failure, and aging characteristics of these materials merit specific study.)
- Ceramic composites for high temperature applications.
- Aluminum reinforced with ceramic fibre as transmission line material.
- Aluminum combined with plastics for automobiles.
- Conducting ceramics for electrochemical reactors.
- Super conducting ceramics.
- Aerogel for use in high R value windows and other insulating applications.
- Alternatives to cobalt bearing alloys in radiation fields.

- Synrock materials for high pressure high temperature pH probes and for rad waste disposal.
- Conductive polymers.
- A leak-plugging substance capable of working in the temperature and radiation environment of a nuclear plant.
- Cementacious matrix composites for specialized structural applications.
- Solid-state processed thermoplasters for enhanced strength and durability in applications of these polymers.
- Polymeric phase change materials for thermal energy storage.

- *Ontario Hydro should in general pay more attention to novel materials*
- *Integrated cementacious/polymer composites for solidification of radioactive wastes*
- *Optically responsive materials for sensors, transducers etc. (to be used with optical fibres as replacements for conventional circuits)*
- *ZnO ceramics for surge protective devices*
- *New alloys with superior corrosion and creep resistant properties for existing and advanced thermal generating stations*
- *Laminated pressure tubes with corrosion resistance and deuterium impermeability on the inner surface*
- *Polymer coatings*
- *Energy storage systems in general*
- *Biotechnology - conversion of waste products and waste heat to useful products*
- *Removal of Sulphur dioxide from gases*
- *Use of natural gas integrated with coal gasification to generate electricity*

G4. (Non-Delphi Question)

If any of the items on the preceding list are in your opinion particularly worthy of the attention of the Research Division, please mention these below with a sentence identifying their merit.

(2) Al - Li alloys for light strong structures.

(2) Li for batteries.

( ) High strength, heat tolerant alloys for tubes in super critical boilers.

(2) Isotope depleted zirconium for pressure tubes and fuel bundles.

( ) Shape memory alloys for tube repairs and heat-sensitive switches.

(2) Glassy metals for heat exchangers and transformers.

( ) Directionally solidified alloys for high-temperature stability of structural components.

(1) Super alloys and duplex stainless steels for flue gas desulphurization equipment.

(2) Metal matrix composites for components with particular strength or durability requirements.

(3) High density ceramics for high temperature heat exchangers, bearings and nozzles.

(2) Ceramic coatings and surface modifications for wear, corrosion, and heat resistance.

( ) Novel inorganic coatings for buried pipelines and cables.

(2) Temperature tolerant polymers for heat exchangers.

( ) Fibreglass reinforced plastics for components requiring corrosion resistance or lightweight strength. (The design constraints, failure, and aging characteristics of these materials merit specific study.)

(4) Ceramic composites for high temperature applications.

(2) Aluminum reinforced with ceramic fibre as transmission line material.

( ) Aluminum combined with plastics for automobiles.

(3) Conducting ceramics for electrochemical reactors.

(12) Super conducting ceramics.

( ) Aerogel for use in high R value windows and other insulating applications.

( ) Alternatives to cobalt bearing alloys in radiation fields.

( ) Synrock materials for high pressure high temperature pH probes and for rad waste disposal.

(3) Conductive polymers.

(2) A leak-plugging substance capable of working in the temperature and radiation environment of a nuclear plant.

(1) Cementacious matrix composites for specialized structural applications.

( ) Solid-state processed thermoplasters for enhanced strength and durability in applications of these polymers.

(1) Polymeric phase change materials for thermal energy storage.

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